RESEARCH ARTICLE

Development and Performance Analysis of Integrated Plantain Flour Processing Machine

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ABSTRACT: Plantain being a perishable fruit, there may be want for it to be processed into flour and different product sorts to increase its shelf life. Hence, this research work presents the design of a process machine for plantain flour production from unripe plantain. An integrated plantain flour processing machine was designed and developed in this study. The average performance indices of the developed machine recorded include the throughput capacity of 36.53kg/hr and machine efficiency of 88.65%. This system dries and pulverizes the peeled and probable sliced unripe plantain into flour with high performance. The proximate composition and functional properties results of the processed flour showed wholesomeness in the product. The usage of unripe plantain flours in the food industry have to be recommended in Nigeria. This will wherein make for good enough plantain grown. Thus, it will assist to enhance the dietary and fitness fame of Nigerians as a result of the high protein and micronutrient concentrations in unripe plantain.

KEYWORDS: Plantain flour, processing machine, Drying, Pulverizing; Efficiency

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INTRODUCTION

The processing of plantain into flour as a means of preserving them from spoilage has increased in recent years. Plantain falls under banana and it is a monocotyledonous perennial and important crop in the tropical and sub-tropical regions of the world [1].*Musaspp*., comprising banana and plantain, are among the world's leading fruit crops. Plantains (*Musaparadisiaca*) is one of the important staple food crops consumed in the tropics after rice, wheat and maize and are obtained in about 120 to 130 tropical countries worldwide [2]. In developing countries of Western, Eastern and Central Africa, plantains, *Musa spp.* are major food staples. Nigeria is the world's top plantain producer [3] and about 70 million people in Africa are estimated to depend on *Musa* fruits for a large proportion of their daily carbohydrate intake [4].

Diverse studies have demonstrated that plantain is an important source of carbohydrates, vitamins C and B6, potassium, antioxidants and pro vitamin A carotenoids [5, 6,7]. The potential of plantain to grow in a wide range of environments and produce fruit all year round makes it an important food security and cash crop[8].

The aggregated world production of bananas and plantains is over 76 million metric tons out of which over 12 million metric tons are harvested yearly in Africa [9]. Out of this large produce of banana and plantains, only few undergo industrial processing mostly for improved preservation and value addition. Food uses of plantain in Nigeria include dodo (fried ripe pulp), boli (roasted unripe–ripe pulp), fufu (boiled and pounded unripe pulp), amala (unripe pulp milled into flour and reconstituted into a thick dough), moin-moin (unripe–ripe pulp milled and steamed), porridge/pottage (unripe pulp boiled with additional ingredients), chips (fried unripe pulp) and dodo Ikire (fried overripe pulp with additional ingredients [8].

Plantain flour is the product of dried and pulverized unripe plantain pulp. Traditional sun drying is the most common method applied in processing plantains into flour but, there are a number of problems associated with it such as weather unpredictability, uneven drying, and the slowness of the process, possible damage of plantain flour by bacteria and insects [10]. The products of plantain flour have nutritional and medicinal values which makes plantain a highly

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sought-after product. The processes involved in plantain flour production are separation into fingers from bunch, peeling, washing, slicing, drying, milling and packaging [11, 12].The traditional processing of plantain into flour takes a lot of time, requires a lot of energy and attention from one stage to the other. Thus, the quality and quantity of the flour produced are usually adversely affected [13].

These traditional approaches have proven to be labor-intensive and time wasting in operation, posing danger to operators' finger by causing injury while peeling. It also produces flour of poor end quality after grinding. Hence, there is a need to develop a mechanized integrated system which slices, dries and pulverizes plantain pulp. This machine will help to eliminate these challenges and yet be effective for both small and large scale processing of plantain. This paper therefore presents the design and development of an integrated process machine for plantain flour production. Hence to solve the problem of hygiene, drudgery, poor quality and others associated with the present methods of producing plantain flour. In order to use plantain flours as ingredients for the food industry, it is necessary to determine the effective methods used for its processing and characterize the resulted plantain flour. Hence, proximate composition and functional properties analysis were conducted.

MATERIALS AND METHODS

Machine description and operation

The machine is made up of drying and milling units, the support frame and electric motor. The frame acts as a rigid support for the various components of the machine. It consist of a 5hp, 3.7kW electric motor as a source of power, gear reducers to slow down the speed from the electric motor, the drying chamber, chain drive, blower to help circulate hot air in other to aid moisture removal within the drying chamber, vent, plantain inlet, bearing, shaft, v-belt, pulley.

Peeled and sliced plantain pulps are fed directly into the drying chamber from the inlet point. At the drying chamber, drying takes place moisture content of the pulps is reduced to required texture. The drying chamber receives the sliced plantain pulps as they are fed and deliver them dried into the milling chamber where they are pulverized. The heaters supply the needed heat for the moisture removal while the blowers circulate the heat round the drying chamber in order to increase the rate of moisture removal.

Design consideration and requirement

The design of the machine considered the following: The sustenance of the plantain quality, flavor and color, Optimal processing time and Minimal Plantain wastage.

Heat requirements: Quantity of heat needed to satisfactorily dry plantain was calculated using equation 1. The rate of $22.918W/cm^3$ was obtained.

$$H = mC_P \Delta T \quad \text{..(1)}$$

Where H is quantity of heat required (J), m is mass of plantain at maximum loading. Cp is specific heat capacity of plantain. ΔT is difference in temperature between the tropical ambient and that of drying.

Determination of the centrifugal force exerted by the hammer

$$F_c = \frac{mv^2}{r} \text{..} (2)$$

The angular velocity of the hammer:

$$\omega = \frac{2\pi rN}{60} \text{..} (3)$$

F_c = centrifugal force exerted by the hammer mill; r= radius of the rotor, m; N= number of revolutions; M= mass, kg; ω= angular velocity, radians/second

***Volume of the milling hopper**:* The milling hopper consists of two segments with the upper frustum portion considered as part 1 and the lower cylindrical portion is considered as part 2.The volume of part 1 (frustum) and part 2 were determined with equations 4 and 5 respectively.

$$V = \frac{1}{3}\pi h(R^2 + r^2 + (Rr)^2) \quad (4)$$

$$V = \pi r^2 \text{h}(5)$$

For part1, given that top diameter is 1.2m, radius is 0.6m, bottom diameter 0.125m, radius is 0.0625m, height is 0.6m, the total volume was obtained as $0.2521m^3$ whereas part 2, with diameter is 125mm, 0.125m, radius of 0.0625m,

height is 120mm, 0.12m was obtained as $0.00147m^3$

Chains and sprockets: This is meant to transmit power of velocity ratio = 1, hence sprockets used are of the same diameter and consist of the same number of teeth.

Design of length of chain: The chains are made up of rigid links which are hinged together in order to provide the necessary flexibility for warping around the driving and driven wheels. They transmit motion and power from one shaft to another, when the distance between the centers of the shafts is short. The exact length of the chain is determined in equations 6 and 7:

That diameter/radius of the pitch circle

$$d = pcosec\left(\frac{180^0}{T}\right)\text{OR} \quad r = \frac{P}{2}cosec(\frac{180^0}{T})\text{---}(6)$$

Therefore the length of chain corresponding to

$$\pi(r_1 + r_2) = \frac{P}{2}(T_1 + T_2) \text{ ---- } (7)$$

$$Length of chain = 838.1mm Or\ 0.8381m$$

Let T_1 = Number of teeth on the larger sprocket,T_2 = Number of teeth on the smaller sprocket, and p = Pitch of the chain.

The nominal length of the belt (A):

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \left(\frac{D_1 - D_2}{4C}\right)^2 \text{ ......}(8)$$

Length of belt B;

$$L = 2C + \frac{\pi}{2}(D_1 + D_3) + \left(\frac{D_1 - D_3}{4C}\right)^2 \text{----- } (9)$$

Where L = Length of the belt, mm; C = Centre distance between driven pulley and the driver, mm (505mm); D_1= Diameter of drive pulley, mm;D_2= Diameter of driven pulley, mm; [14]. Length of belt A = 1369mm or 1.37m; Length of belt B = 969mm or 0.969m

Shaft design: To determine the diameter of the shaft, Torque transmitted;

$$T = \frac{P \times 60}{2 \times N \times \pi}\text{------}(10)$$

where the power of the electric motor is 3.7KW and has an RPM of 1182, therefore;

$$T = \frac{3700 \times 60}{2 \times 1182 \times \pi} = 29892N - mm$$

Rigidity of the shaft material,

$$\theta = 0.25° \equiv 0.25 \times \frac{\pi}{180} = 0.0044rad$$
$$L = 0.67m$$

$$modulus of rigidity for steel shaf = 77.2GPa$$

Given that;

$$J = \frac{T \times L}{G \times \theta}$$
$$\frac{\pi d^4}{32} = \frac{T \times L}{G \times \theta}$$
$$\frac{\pi d^4}{32} = \frac{29892 \times 670}{77.2 \times 10^3 \times 0.0044}$$
$$d = 30mm$$

Bearing Design: The bearing type is selected for the use is roller bearing. From the design, the shaft diameter Ds is equal to 30mm. Thus, Bearing bore = 0.03m. Thus using Conrad-type bearing table, we obtained the following data: Bore diameter Di = 30mm; Outside diameter, Do = 57.2mm; Bearing ball per roll, Z = 12; Dynamic basic rating capacity is C_d = 21000N.

Fabrication of Machine

Having selected the required materials and the design of the integrated plantain flour processing machine, the fabrication process was next. The procedure considered and employed in the production of the machine includes: welding, grinding drilling and turning processes.

The frame was fabricated using a mild steel angle iron. The height and width of the main frame was marked out to be 772.2mm and 852.4mm respectively. The outlet chute consists of a rectangular stainless steel plates. The chute was cut into a dimension of 70mm by 70mm and a handle attached to enable opening whenever discharge is required and closed whenever feeding is required. The inlet chute consists of a rectangular stainless steel plates. The chute was cut into a dimension of 50mm by 30mm. It is attached to the dryer section.

The angle irons cut into pieces were permanently welded to form the frame to enhance stability. The bearings and the electric motor were firmly bolted to their respective positions on the frame. The grinding belt and the belt connected to the gear reducer for the

rotation of the dryer were then fixed upon the pairs of the pulleys. An engagement system was constructed to enable engage and disengage the dryer belt whenever feeding is required. Finishing touches was carried out where necessary on the assembled machine for enhanced beauty and aesthetics. A pictorial representation of the assembled machine is seen in Fig. 1:

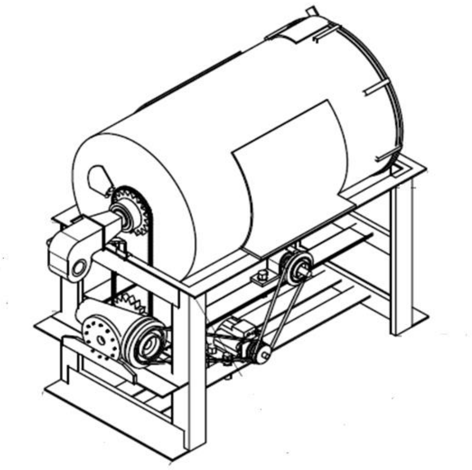

Figure 1 Integrated Plantain flour processing Machine

Performance Evaluation Procedure

The plantain materials used for the performance evaluation of the machine were purchased from Nkwo Market, Aba, Abia State, Nigeria. They were peeled and sliced for processing. The integrated Plantain processing machine was evaluated by investigating the effects of the Plantain drying temperature and rotor speed in the drying chamber. Experiments were carried out in which the speed of the drying chamber rotor was operated at 79 rpm. At each instance, known mass of chipped plantain were introduced into the drying chamber and the time taken to dry and pulverize was noted using a stopwatch. After that, the mass of plantain flour received at the chute was weighed and recorded.

The integrated plantain processing machine test performance indicators includes the Overall machine throughput capacity, $T_p(\text{kg/hr.})$, Machine efficiency , η_{pm} (%).
The efficiency of the machineη_{pm} (%), was obtained using equation 11

$$\eta_{pm} = \frac{\text{Outputweightof flour}}{\text{InputWeightof dried plantain}} \times 100 \ldots (11)$$

The overall machine throughput capacity, $T_p(\text{kg/hr.})$ which is the total mass of processed plantain flourM_p per unit time$T$was calculated using equation 12.The total time required for processing of plantain which includes time for pulverization unit, milling unit and drying unit. Fig. 2 shows the fabricated machine tested for its performance.

$$T_p \quad = \frac{M_p}{T} \text{------} (12)$$

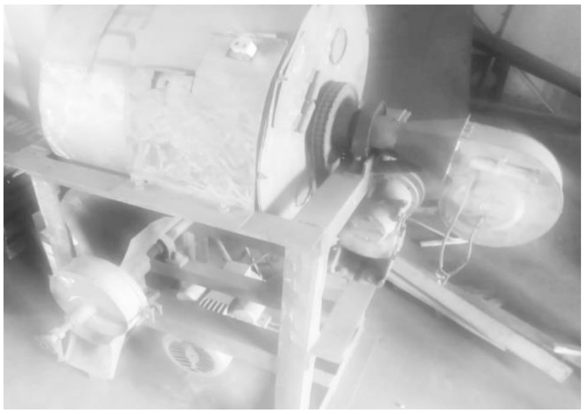

Figure 2Fabricated plantain flour processing machine

Analysis of Processed Flour

The processed flour was subjected to some qualitative examination of proximate composition and Functional properties analysis. This was undertaken at Emery Research Laboratory, located at Ahiaeke, Umuahia, Abia State, Nigeria. Proximate Analysis of Unripe Plantain Flour was carried out after processing to determine the wholesomeness of the product. The parameters used include: Determination of Moisture Content which was determined by the gravimetric method described by AOAC [15].The weight of moisture loss was determined by difference and expressed as a percentage of the sample analyzed. It was calculated using the formula:

$$\%\, MoistureContent = \frac{W_b - W_c}{W_b - W_a} \times 100 \text{ -----} (13)$$

Where: W_a= Weight of empty dish,W_b= Weight of empty dish + sample before drying,W_3= Weight of empty dish + sample after drying.

Determination of Ash Content which was done by furnace incineration gravimetric method described by AOAC [16].The weight of the ash was obtained by difference and expressed as a percentage of the weight of the sample analyzed. It was calculated using the formula:

$$\% \, AshContent = \frac{W_b - W_a}{W_c} \ldots\ldots (14)$$

Where: W_a= Weight of empty crucible, W_b= Weight of crucible + ashes, W_c= Weight of sample.

Protein content of the samples was determined by Kjeldahlmethod described by [17].Fat content of the samples was determined by the continuous solvent extraction method using a soxhlet apparatus. The method described by [17] was used. Determination of Crude Fiber Content was done by the gravimetric method described by [15].The carbohydrate content was determined.

Furthermore, the functional properties were also determined. This involves the determination of Swelling Index (SI), which was determined as the ratio of the swollen volume to the ordinary volume of a unit weight of the flour. Water Absorption Capacity (WAC), Oil Absorption Capacity (OAC) and Emulsion activity and emulsion stability were also determined. Lastly, Bulk Density and Gelatinization temperature were also determined.

RESULTS AND DISCUSSION

In the drying chamber, fresh chipped plantain samples of 14kg were introduced for drying. The drying of the plantain was done at temperatures ranging from 80 to 150°C. An average mass of 4.55kg of dried plantain was obtained. It was observed that the higher the temperature, the plantain dried faster (Fig.3). The drying chamber rotates at an approximate speed of 79rpm with 5hp electric motor.

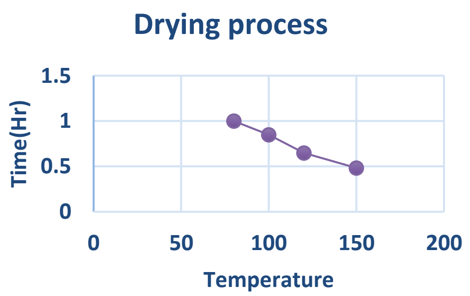

Figure 3Effect of drying temperature on drying time

The milling process was next with the dried samples of the plantain fed into the chamber of 4kg mass. The mass of Plantain flour obtained after milling was approximately 3.62kg. This was achieved in 0.12hr. The performance test to affirm the effectiveness of the machine was done. Machine efficiency of 88.65% was recorded and throughput of 36.53Kg/hr (Table 1).

Table 1: Performance test result of Machine

Exp. Runs	Machine Efficiency (%)	Throughput (Kg/hr)
1	89.20	36.30
2	88.50	38.45
3	87.80	34.25
4	89.40	36.00
5	88.36	37.65
Average	**88.65**	**36.53**

Proximate Composition and Functional properties of Plantain Flour

The result of the proximate composition of unripe plantain flour was presented in table 2. The moisture of the unripe plantain flours was 8.80%, and it was evident that drying caused significant decrease in moisture content of the processed flour. The low moisture content ensure the inhibition of microbial growth, hence is an important factor in food preservation. The ash content of the flour was 3.00%indicating that the processed unripe plantain retained the minerals present. The fat content of the sample gave 1.20%. The observed low percentage fat content in the flour sample is attributed to the fact that tubers mainly store energy in form of starch instead of fat [18]. The crude fiber content of the flour was 1.50%. Crude fiber represents the content of the non-digestible components of food. These are essential in animal nutrition [19].The protein content of the flours was 4.62%.The carbohydrate content of the flour was quite high (80.87 %).

The results of the functional properties of the unripe plantain flour are presented in table 3. The Water Absorption Capacity (WAC) of the flour was 1.80g/g which was higher than the range (0.76 to 1.68 g/g) reported for wheat-plantain flours by [20]. This increase in WAC could be attributed to their higher starch content. The Oil Absorption Capacity (OAC) of the flour was 2.40g/g. The Swelling Index (SI) of the flour was 1.07. Therefore, high swelling index is an important criterion for good quality flour [21]. The Emulsion Capacity (EC) of the flour was23.52%. In this study, Bulk Density (BD) of the unripe plantain flour was0.590 g/ml

which was lower than 0.71 g/cm^{3}to 0.86 g/cm^3 reported for wheat flour [22]. This lower BD could be advantageous in the formulation of baby foods where high nutrient density to low bulk density is required [20]. The gelatinization temperatures of dried flour (78°C) were obtained. The higher values of GT in the flours could be due to their higher starch content [23].

Table 2: Proximate composition of unripe plantain flour

Flour Sample	Moisture	Ash	Fat	Crude fiber	Protein	Carbohydrate
	8.80±0.28	3.00±0.00	1.20±0.00	1.50±0.00	4.62±0.17	80.87±0.45

Values are means ± standard deviations of duplicate determinations (p<0.05)

Table 3: Functional properties of unripe plantain flour

Flour Sample	WAC (g/g)	OAC (g/g)	SI	EC (%)	BD (g/ml)	GT (°C)
	1.80±0.14	2.40±0.14	1.07±0.00	23.52±0.17	0.590±0.002	78.00±0.00

Values are means ± standard deviations of duplicate determinations (p<0.05)

CONCLUSION

An integrated plantain flour processing machine was designed and developed in this study. The average performance indices ofthe developed machine recorded include the throughput capacity of 36.53kg/hr and machine efficiency of 88.65%.This machine dries and pulverize the peeled and probably sliced unripe plantain into flour with high efficiency. This is however converse to the traditional method of producing plantain flour that is cumbersome, unhealthy, and time consuming. Therefore, the machine can be used to process plantain for both domestic and commercial use. The machine is user-friendly, requires no skilled labor, and can be employed by small and medium scale food processors. In addition, the proximate composition and functional properties results of the processed flour showed wholesomeness in the product.

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